

# Low-Intensity States in the Neutron Star X-ray Binary Aql X-1

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## Abstract

Aql X-1 was observed in a Low Intensity State (LIS), a state that is usually characterized by high optical but low X-ray flux. Our daily monitoring of the source using the 1.3m telescope in Cerro Tololo Inter-America Observatory operated by the Small and Moderate Aperture Research Telescope System (SMARTS) was used to trigger a series of target-of-opportunity (ToO) observations of the source using the Rossi X-ray Timing Explorer satellite (RXTE). The X-ray colors and temporal variability studies suggest that the source was in a powerlaw dominated state featuring high rms variability in the lightcurve and dominance of hard photons during this LIS. The ToO observations were continued until the source made a transition to the canonical thermal dominated or high/soft state.

*Key words:* accretion, accretion disks — stars, neutron stars — X-rays, binaries — individual (Aql X-1)

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Aql X-1 is a well studied transient neutron star X-ray binary (NSXRB) system that goes into outburst about once every year. Since its launch, the RXTE has observed 5 major outbursts from this source that follow the typical Fast Rise and Exponential Decay (FRED) lightcurve morphology (1). Besides these major outbursts, many small scale activities have been noted that were clearly non-FRED (see Fig. 1). Reg-

ular monitoring in optical/IR (OIR) bands have revealed that the OIR flux during some of these minor X-ray activities can become comparable to the peak OIR flux during normal outbursts.

Detection of Aql X-1 in hard X-rays using the INTEGRAL satellite was reported by Molkov et al. (2) and also in optical by Ilovaisky and Chevalier (3), after it came out from behind the Sun in mid-March 2004. During mid-May 2004 it showed signs of coming out of this prolonged LIS (4) and entering a full outburst. Here we

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present the results of our pointed X-ray observations of the source during May-June 2004.

Preliminary study of the X-ray colors and variability (Fig. 2 and Fig. 3) shows that during the LIS, the X-ray state is very similar to the canonical powerlaw dominated or low/hard state with high rms variability and frequent type I bursts. The total  $\sim 2$ -60 keV flux remained at a fairly constant level till MJD 53161 and then started increasing steadily till around MJD 53165 when the state transition to the thermally dominant state occurred. After the transition the flux (and the associated mass accretion rate) started increasing rapidly, reaching a peak around MJD 53167.7, and then falling sharply again. We do not see any evolution of colors during the LIS, however the colors became much softer after the transition, most likely due to the formation of an accretion disk. The rms variability also drops significantly after the transition. Detailed study is in progress.

Analogous events have been observed in another NS system 4U 1608-52 and few black hole systems XTE J1550-564, GRO J0422+32, GRO J1719-24, XTE J1118+480 as well (see (5; 6; 7) and references therein) where sometimes the system fails to come out of the hard state during the entire outburst. During the 2004 outburst, Aql X-1 entered the regular outburst state *after* the LIS. The reverse case, when a regular FRED outburst occurred *before* the LIS, was also seen in the same source during 1998, as shown in Fig. 1(a).

## Conclusions

- The morphology of the optical/X-ray lightcurve is highly non-FRED during LIS, for both neutron stars as well as black holes.
- The spectral and temporal characteristics of the LIS is similar to that of the canonical powerlaw dominated or low/hard state.
- The transition from the LIS to an X-ray bright, thermal dominated state is rapid ( $< 1$  day).
- The hard 15-250 keV X-ray flux in this case attained a maximum almost simultaneously with the maximum of the optical flux and decayed rapidly as the source entered the thermal dominant state.

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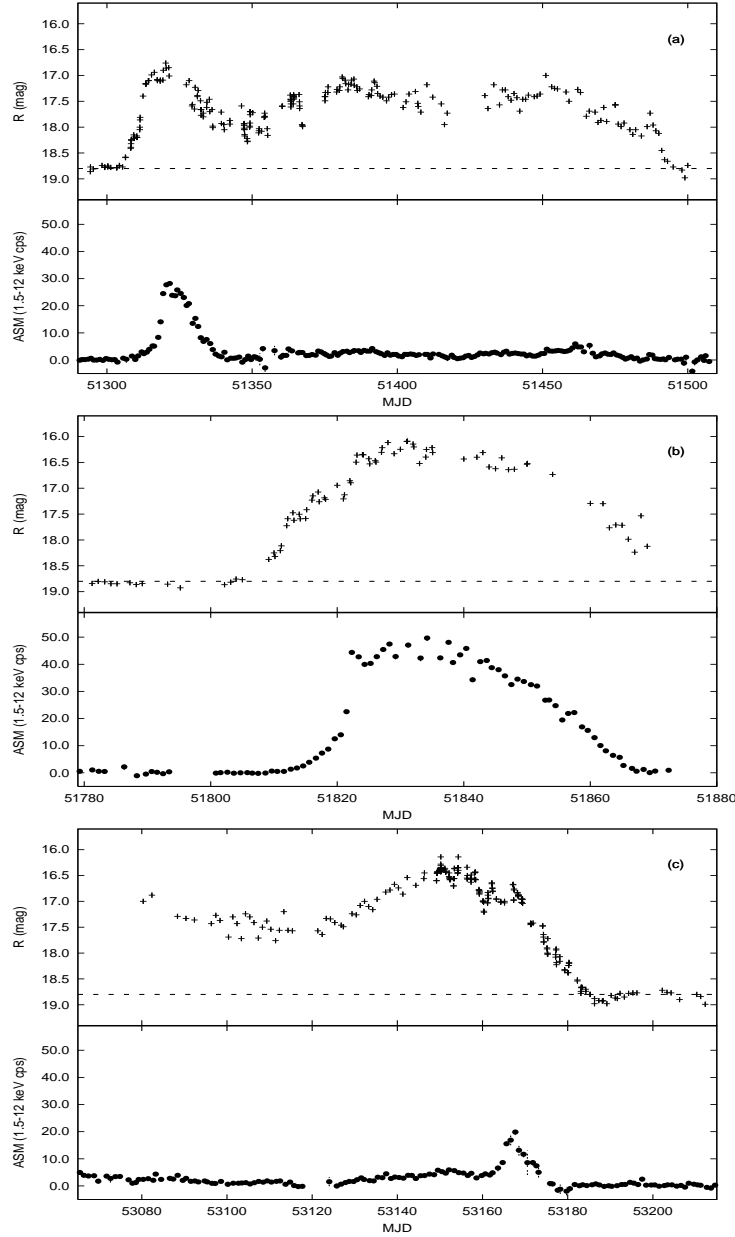


Fig. 1. Different types of outburst in Aql X-1. In panels (a), (b) and (c) we show the R band as well as ASM activity during three outbursts. The R band data was taken using the SMARTS 1.3m telescope in CTIO, Chile. ASM data courtesy the ASM team at MIT. Panel (a): A FRED followed by an extended LIS during 1998. Panel (b): A normal outburst with FRED profile during 2000. Panel (c): An extended LIS followed by a transition to the soft state during 2004 (Maitra and Bailyn, in preparation). The lack of data during the end of (b) and the beginning of (c) is because the source was too close to the Sun to observe at night. The dotted line in the optical panel is the mean quiescent brightness of Aql X-1. The quiescent X-ray flux is below ASM detection limits.

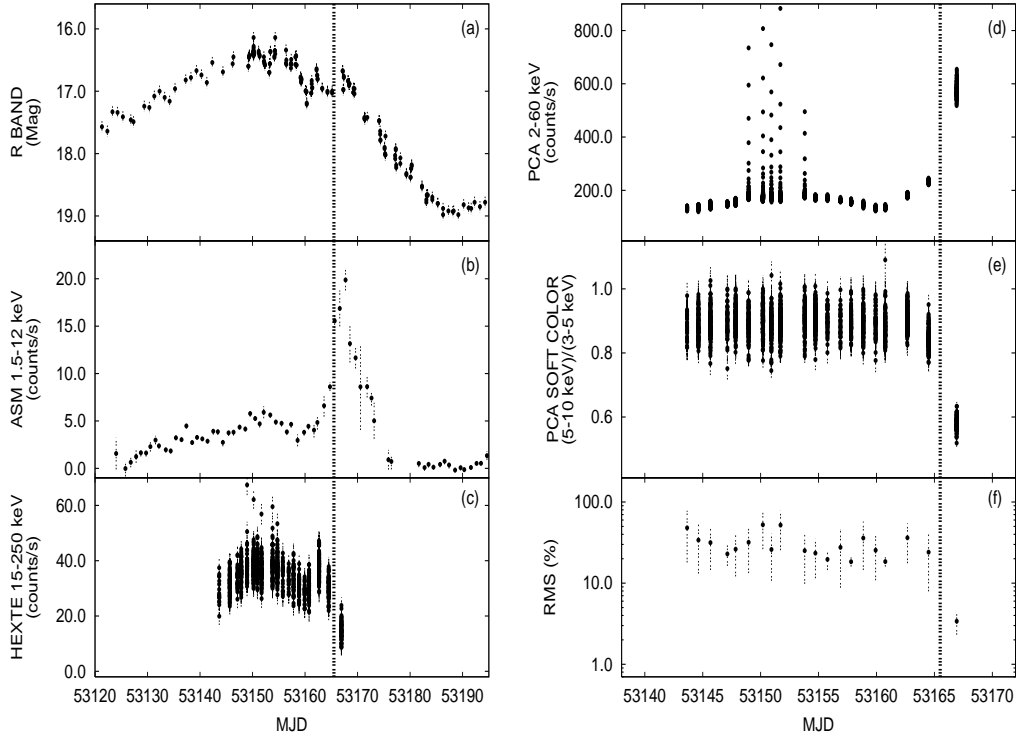


Fig. 2. The evolution of lightcurve, colors and rms variability during the outburst of June 2004. The dotted line marks the transition from a powerlaw dominated to a thermal dominated state. Panel (a): Optical R band lightcurve from SMARTS. Panel (b): RXTE ASM 1.5-12 keV X-ray lightcurve. Panel (c): RXTE HEXTE 15-250 keV hard X-ray lightcurve. Note that the HEXTE lightcurve peaks about the same time as the optical does. Also remarkable, is the sharp decline in HEXTE flux right after the transition to soft state. Panel (d): RXTE PCA 2-60 keV lightcurve. Note the frequent type I bursts from MJD 53147-53155 and the sharp rise in flux after the state transition. Panel (e): The hardness of the source given by the ratio of counts in hard to soft band also drops abruptly, marking the transition from one state to another. Panel (f): The rms variability of the incident photon flux between, in the frequency range of 0.01-10 Hz also shows sharp changes during state transition.

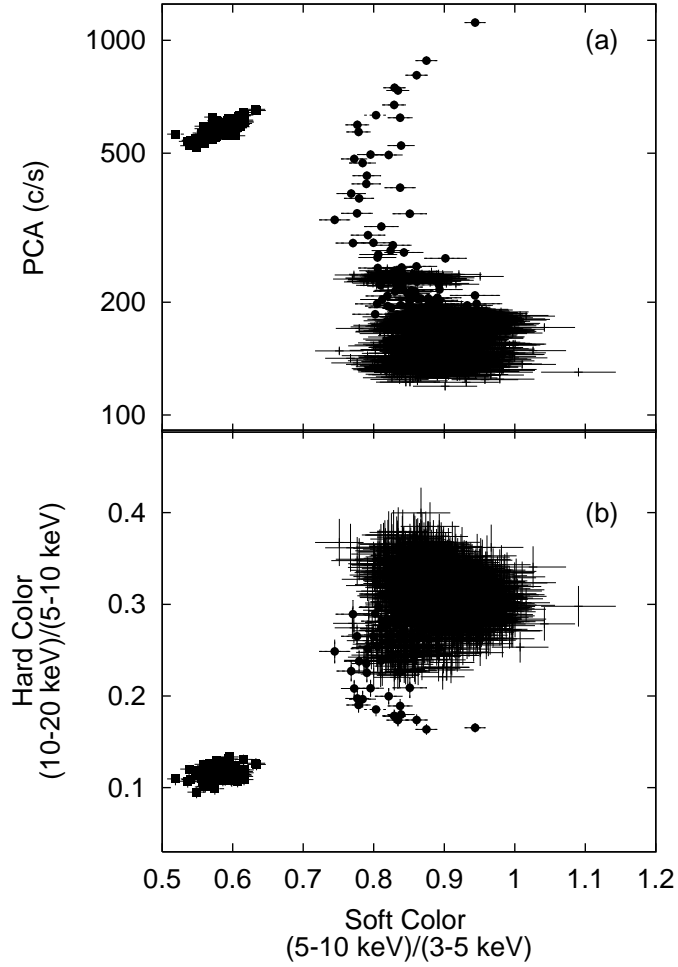


Fig. 3. The color-luminosity and color-color diagrams respectively show clearly the two distinct spectral nature of the source before and after the state transition. The soft state is the small island in the left side of both plots shown by filled squares (■), the hard state, with more data-points and larger scatter occupy the island on the right side shown by plus symbols (+). The filled black circles (●) are data during type I bursts and hence are clear outliers compared to the rest of the data.